

THE SPECTRAL PROPERTIES OF INTERPLANETARY DUST PARTICLES

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The majority of the infrared transmission (absorption) spectra of individual interplanetary dust particles (IDPs) can be classified into one of three infrared classes based on the spectral profile of their $10\mu\text{m}$ silicate features (see Fig. 1). These three classes have been referred to as the olivines, the pyroxenes, and the layer-lattice silicates, after the terrestrial and meteoritic minerals that provide the best match to the observed $10\mu\text{m}$ band profiles (Sandford and Walker, 1985). Transmission electron microscopy and electron diffraction studies confirm that particles in the three infrared classes are, in fact, dominated by the appropriate mineral types (see Walker, Bradley, and Sandford, 1987, for a recent review of the properties of IDPs).

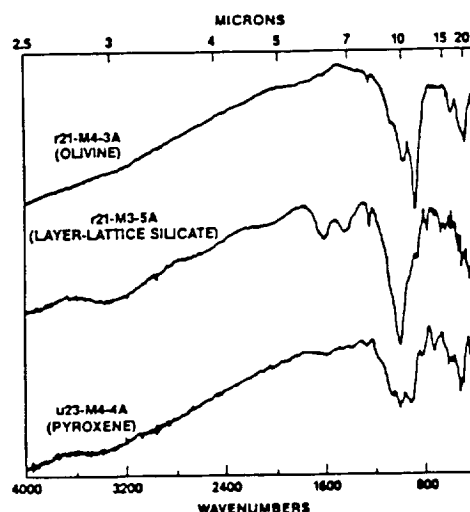


Figure 1. Representative spectra from IDPs in each of the three infrared classes. Figure adapted from Sandford and Walker, 1985.

Particles falling in the olivine and pyroxene infrared groups are dominated by the appropriate anhydrous mineral grains (Christoffersen and Buseck, 1986; Bradley and Brownlee, 1986). These particles are "coarse" grained in the sense that they contain mineral grains having diameters between 0.1 and 2 microns. These particles often have "fluffy" morphologies and consist primarily of single-mineral grains embedded in carbonaceous matrix. Diffraction studies show that the majority of the silicates are crystalline in nature, rather than amorphous. The carbonaceous material typically constitutes 2-8 percent of the particles by mass. The infrared spectra of these particles are dominated by the " $10\mu\text{m}$ " (Si-O-stretching mode) and " $20\mu\text{m}$ " (Si-O-Si-bending mode) features of crystalline silicates.

Particles in the layer-lattice silicate infrared class are usually dominated by smectic minerals (Tomeoka and Buseck; 1984, 1985) with a small minority containing primarily serpentines (Bradley and Brownlee, 1986). This is opposite of the case seen in meteorites where serpentines are observed to be the major layer-lattice silicates present. These particles represent the most common type of IDP in the stratospheric collections, and they tend to be more compact than the IDPs dominated by olivines and pyroxenes. Carbonates are

an important secondary mineral seen in most of the IDPs in this infrared class (Sandford and Walker, 1985; Sandford, 1986; Tomeoka and Buseck, 1986) are the source of the prominent $6.8\mu\text{m}$ feature seen in the spectra. Also apparent are the 3.0 and $6.0\mu\text{m}$ features due to adsorbed and absorbed water. As with the particles in the other two infrared classes, these particles contain about 5 percent carbonaceous material by mass.

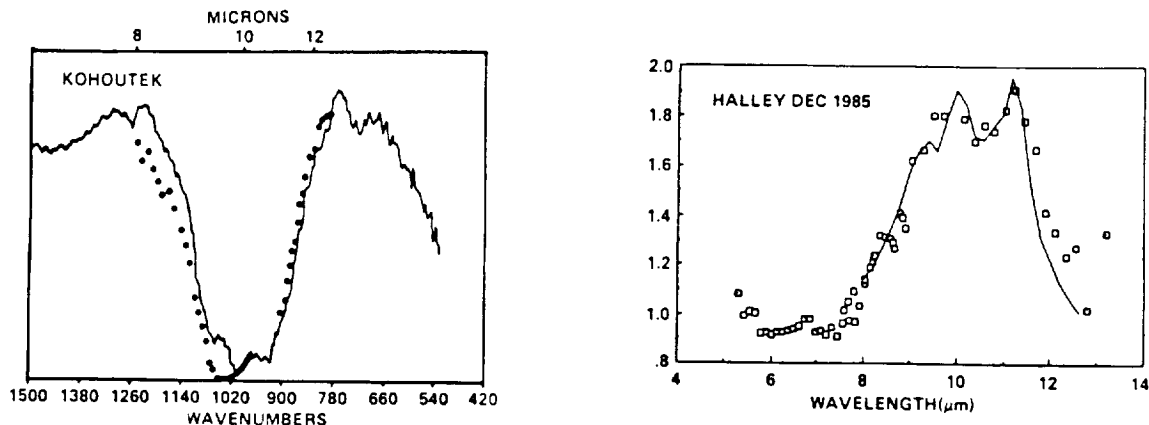


Figure 2. Comparison of the infrared emission from Comets Kohoutek and Halley with IDP spectral mixtures. The points are the cometary data; the solid lines are the IDP data. Figures adapted from Sandford and Walker, 1985, and Bregman *et al.*, 1987

To first order, the $10\mu\text{m}$ emission spectra of comets Kohoutek and Halley can be matched by combinations of these spectral types (see Fig. 2) (Sandford and Walker, 1985; Bregman *et al.*, 1987). In the case of comet Halley, a reasonable fit is provided by a combination containing approximately 55 percent olivines, 35 percent pyroxenes, and 10 percent layer-lattice silicates. In contrast, the comet Kohoutek silicate feature cannot be fit using mixtures that contain more than a few percent of the olivine-rich IDPs. This suggests that different comets may have different overall compositions. Given comet Halley's observed variability, we need to also consider the possibility that the relative mix of particle types ejected could vary from time to time within a single comet. It is interesting to note that the detailed features in the comet Halley $10\mu\text{m}$ data imply the presence of crystalline silicates, in contrast to the featureless interstellar 10-micron feature, which is generally thought to indicate the presence of amorphous silicates. The dominance of anhydrous minerals such as olivine and pyroxene in Halley (as inferred from the spectra) is consistent with the compositional constraints determined by the various Halley space-probe dust experiments (by Brownlee, this volume). The presence of at least some layer-lattice silicates in comet Halley is suggested, however, by the observation of a weak $6.8\mu\text{m}$ emission feature in the Halley data that has a strength consistent with the presence of carbonates in the abundance with which they are seen in IDPs.

Note from Figure 1 that the three different infrared types have " $20\mu\text{m}$ " features that fall at different spectral positions, and that in many cases this "feature" actually consists of several bands. These features are due to Si-O-Si-binding- and silicate-lattice-mode vibrations, and hence are more sensitive than the $10\mu\text{m}$ Si-O-stretching band to (i) cation substitution, (ii) crystalline order, and (iii) molecular symmetry. Thus, given that a combination of silicates is required to match the Halley $10\mu\text{m}$ data and the compositional information returned by the Halley space probes, we wouldn't expect a single " $20\mu\text{m}$ " band, but instead a series of overlapping features of varying widths and strengths. The net result should be a broadband excess near $20\mu\text{m}$ in which there may be no strong, obvious "narrow" features.

Despite the fact that the mass in IDPs is dominated by silicates, the interaction of the dust with visible photons is primarily mediated by the carbonaceous material (see Fig. 3). Intense bands in the Raman spectra of IDPs at 1350 and 1600 Δcm^{-1} and a broad feature between 2200 and 3300 Δcm^{-1} are characteristic of the presence of aromatic domains whose size scale is less than 25 Å (Allamandola, Sandford, and Wopenka, 1987). No spectral evidence exists for the presence of graphite within the IDPs. The absence of silicate bands in the Raman spectra demonstrates that the carbonaceous material effectively covers the silicates in the IDPs and "screens out" visible light through scattering and absorption before it reaches the silicates. This observation has important implications for the modeling of cometary thermal emission (see, for example, Krishna Swamy *et al.*, 1987, this volume). Little else is known about the composition of the carbonaceous component in IDPs except that the material contains C and H, with minor amounts of O and N (Bradley, Brownlee, and Fraundorf, 1984), and some small fraction of this material is the carrier of a phase enriched in deuterium (McKeegan, Walker, and Zinner, 1985). Presumably this material is similar to the polymeric phase seen in meteorites (Hayatsu and Anders, 1981), which consists of small aromatic domains randomly interlinked by short aliphatic bridges.

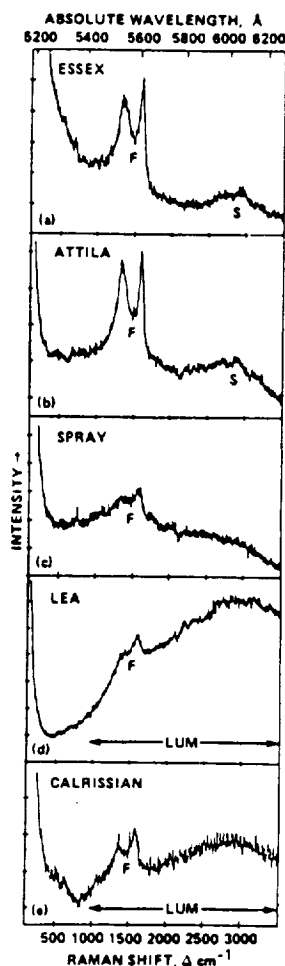


Figure 3. Raman spectra of five interplanetary dust particles. Figure adapted from Allamandola, Sandford, and Wopenka, 1987.

In brief, the observed spectral and mineralogical properties of IDPs allow us to conclude the (i) the majority of IDP infrared spectra are dominated by olivine, pyroxene, or layer-lattice silicate minerals, (ii) to first order the emission spectra of comets Halley and

Kohoutek can be matched by mixtures of these IDP infrared types, implying that comets contain mixtures of these different crystalline silicates and may vary from comet to comet and perhaps even within a single comet, (iii) we probably do not expect to observe a single "20 μ m" feature in cometary spectra, (iv) carbonaceous materials dominate the visible spectra properties of the IDPs even though the mass in these particles consists primarily of silicates, and (v) the particle characteristics summarized in items (ii) and (iv) need to be properly accounted for in future cometary emission models.

References

- Allamandola, L. J., Sandford, S. A., and Wopenka, B., 1987, *Science*, **237**, 56-59.
 Bradley, J. P. and Brownlee, D. E., 1986, *Science*, **231**, 1542-1544.
 Bradley, J. P., Brownlee, D. E., and Fraundorf, P., 1984, *Science*, **223**, 56-58.
 Bregman, J. D., Campins, H., Witteborn, F. C., Wooden, D. H., Rank, D. M.,
 Allamandola, L. J., Cohen, M., and Tielens, A. G. G. M., 1987, *Astron. Astrophys.*,
 in press.
 Christoffersen, R. and Buseck, P. R., 1986, *Earth Planet. Sci. Lett.*, **78**, 53-66.
 Hayatsu, R. and Anders, E., 1981, *Topics Curr. Chem.*, **99**, 1-37.
 Krishna Swamy, K. S., Sandford, S. A., Allamandola, L. J., Witteborn, F., and Bregman,
 J. D., 1987, *Icarus*, submitted.
 McKeegan, D. K., Walker, R. M., and Zinner, E., 1985, *Geochim. Cosmochim. Acta*, **49**,
 1971-1987.
 Sandford, S. A., 1986, *Science*, **231**, 1540-1541.
 Sandford, S. A. and Walker R. M., 1985, *Astrophys. J.*, **291**, 838- 851.
 Tomeoka, K. and Buseck, P. R., 1984, *Earth Planet. Sci. Lett.*, **69**, 243-254.
 Tomeoka, K. and Buseck, P. R., 1985, *Nature*, **314**, 338-340.
 Tomeoka, K. and Buseck, P. R., 1986, *Science*, **231**, 1544-1546.
 Walker, R. M., Bradley, J. P., and Sandford, S. A., 1987, in *Meteorites and the Early Solar
 System*, (J. Kerridge, ed.), Univ. of Arizona Press, in press.

DISCUSSION

HUFFMAN: You can get a double-peaked Raman spectrum from many materials including graphite (well-ordered) that has simply been rubbed against a surface, not just from "amorphous" carbon.

SANDFORD: Yes, this is true. The presence of the double hump only tells you that the aromatic C-C bonds are present and the domains of order are limited in size (25 Å in IDPs). The ease with which the graphite spectrum (Raman) is altered and the lack of crystalline graphite seen in IDPs shows that the optical constants of graphite are not appropriate for cometary modeling.

RUSSELL: It appears to me that the difference between Halley and Kohoutek is that one is "processed" — heated to produce crystallinity — whereas the other is not. The nucleus of Halley is heated during each apparition, undergoes "night" and "day" thermal cycling, experiences pressure buildups and releases (jets and outbursts), and thus the top few meters (up to 100m, based on two outbursts observed in the infrared post-perihelion) are likely not "pristine."

SANDFORD: A smear of pyroxenes can mimic an amorphous 10 μm feature.

HANNER: We have been discussing comparisons between laboratory transmission spectra and comet emission spectra. One has to be a bit careful, for the shapes can differ, due to a scattering contribution in the transmission spectra and a range of grain sizes and temperatures contributing to the emission spectra.